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ABSTRACT

This research begins to refine a cognitive model of interactive information seeking for use in the design of information retrieval (IR) systems. The research reported in this paper critically examines several interactive information seeking and retrieval models that have emerged over the last two decades. Building primarily on the stratified model, interactions are identified at the surface stratum that can be utilized to design information retrieval systems that infer intentions at other strata, thereby better assisting users during the search process. This paper presents (1) the development technique utilized to modify and (2) the existing IR system that monitors these interactions and recommends search tactics to the user. The result is an increase in the performance of an IR system, as measured by precision. (Contains 28 references.) (Author)

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Towards Implementing a Cognitive Model of Searching

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Abstract This research begins to refine a cognitive model of interactive information seeking for use in the design of information retrieval (IR) systems. The research reported in this article critically examines several interactive information seeking and retrieval models that have emerged over the last two decades. Building primarily on the stratified model, interactions are identified at the surface stratum that can be utilized to design information retrieval systems that infer intentions at other strata, thereby better assisting users during the search process. This paper presents the development technique utilized to modify an existing IR system that monitors these interactions and recommends search tactics to the user. The result is an increase in the performance of an IR system, as measured by precision.

Introduction

This research begins the refining a cognitive model of IR searching to a level of granularity useful in the design of an IR system. End user searching on traditional information retrieval (IR) systems, on-line public access catalogues, Web search engines, and digital libraries has become the primary method of locating information for many people. With the advent of end-user searching, numerous cognitive models of information seeking and retrieval have been proposed. Unfortunately, many of these cognitive models seem to be in a perpetual state of early development and have not taken the next, critical step in refining the models. Presently, many IR cognitive models are not sufficiently developed for the design of IR systems, with the result that current systems may not effectively or efficiently support users' information seeking needs.

This article begins with a review and critique of cognitive models for information seeking and retrieval. One model that is discussed at some length is the stratified model. Building on this model, modifications to the surface stratum that take advantage of the entire range of user – system utterances, not just the query, are presented, along with how these interactions relate to the user's cognitive and situational strata. A development technique is presented to utilize these interactions in the design of an IR system. An existing IR system is modified using this approach. The article contains a discussion on the improved system, the results of a user evaluation, and then concludes with recommendations for future research.

Related Research

Cognitive models have been successfully utilized in human – computer interaction, and research is now underway to incorporate cognitive models within sets of design tools (Ritter, et. al., 2001). However, research into cognitive models of interactive searching on IR systems is still at an incipient stage, despite a large body of research on user – system interaction. Researchers have investigated many aspects of interactive searching, including queries, search terms, sessions, and feedback, among other factors (Saracevic, et. al., 1988; Saracevic, et. al. 1991; Spink & Saracevic, 1997).

However, Ellis (1984) has pointed out the flaws of attempting to develop a theoretical searching model utilizing this approach. These empirical studies have focused on the observed elements of searching as it currently is

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exhibited, usually taking a grounded theory approach (Strauss & Corbin, 1990). The data gathered in these studies may not translate to other user populations or IR systems. In this respect, the "knowledge derived from the testing is uncertain" (Ellis, 1984, p. 25). As Ellis predicted, indications are that the results from these studies are only specific to a particular IR environment (Jansen & Pooch, 2001). Because of these potential shortcomings, a theoretical approach to IR research on user – system interaction is needed (Saracevic, 1996).

From a theoretical approach, there are numerous cognitive models of interactive IR systems (Bates, 1979; Belkin, et. al., 1989; Ellis, 1997; Ingwersen 1996; Saracevic 1997). All have similar goals, usually to (1) document the interaction between the user and IR system, (2) identify patterns, (3) relate the patterns to retrieval effectiveness, and (4) incorporate those patterns that will increase the performance of IR systems into the designs of IR system mechanisms (Saracevic, 1996). However, no one has yet sufficiently developed any of these models to a level where one can conduct empirical tests or utilize them for IR system design (Saracevic, 1997; Spink, et. al., 1998). In fact, Ellis (1992) points out that it is difficult to identify "any particular achievement which stands out as exemplar" (p. 52) using the cognitive modeling approach to IR. Almost a decade later, Ellis's statement is still valid. Some of the many cognitive models are discussed and critiqued below.

Traditional IR Model

As presented by Robertson (1977), the traditional IR model contains a system and a user. The system has several information objects that are organized in some manner. The user has an information need that is represented by a query acceptable to the system. The system performs the matching between the query and the information objects, presenting the results to the user. There is a feedback function that allows for the user to modify the query based on the previous results list. Although the traditional model addresses a component of the search process, there are several weaknesses. For example, the model assumes that the query accurately represents the user's information need. The traditional model also fails to consider users' cognitive needs, user behaviors, interactive searching, and user gaps in knowledge (Spink, et. al. 1998).

Cognitive Models of Interactive IR

As end user searching continues to proliferate, several cognitive models specific to interactive IR have been proposed, including those derived from observed user behaviors during the information seeking process. Bates (1979) presents several search tactics grouped as monitoring, file structure, search formulation, and term. Bates suggests that the collection of these tactics represents a model of IR seeking with users adopting different tactics for different information needs or environments. However, similar to the traditional model, these different tactics fail to consider actual user needs, situations, knowledge gaps, and disconnections between the system and user.

Bates (1989) suggests a berry-picking model of information retrieval where the information is scattered around like berries around bushes. The information need is not satisfied by a single set of results but rather by selecting a series of information bits along the way. The information need as represented by the query is continually shifting as the user moves through a variety of information sources. As the user discovers new information, new ideas and directions of search may emerge.

Although anecdotally, one can relate the IR process to this berry-picking model, from a system design perspective, there is not enough detail to develop IR. For example: What is a berry? How is it different from non-berries? How does the user distinguish the berries from the non-berries? What are the causes for the changes in directions? How can these causes be coded? How is the model to be evaluated within the accepted IR metrics of recall and precision?

Cognitive Models of IR in Hypertext Environments

With the Web affecting almost every facet of information seeking, several cognitive models specifically addressing a hypertext environment have emerged. Marchionini (1995) proposes a model, based on the behavioral model of Ellis (1989) but accounting for the browsing aspects of hypermedia environments. In the Marchionini model, the information seeking process is composed of eight sub-processes that develop in parallel

(Marchionini, 1995, p. 49-60). The eight sub-processes are: (1) *Recognize and accept an information problem*, (2) *Define and understand the problem*, (3) *Choose a search system*, (4) *Formulate a query*, (5) *Execute search*, (6) *Examine results*, (7) *Extract information*, and (8) *Reflect, iterate, and stop*. Unlike Ellis's version (1989), this model describes a process rather than independent behaviors; however, the issues of implementation in the design of an IR system still remain.

A web user 'taskonomy' (Byrne, et. al., 1999) has taken a grounded theory approach to classify logical groupings of information seeking tasks on the Web. This model identifies six main categories of user actions within a hypertext environment, which are:

- *Use information*: Read, view, listen, save to disk, duplicate, print, etc.
- *Locate on page*: Something "interesting," related concept, tagged information, etc.
- *Go to page*: Hyperlink, back, forward, bookmark, check history list, provide URL, etc.
- *Provide information*: Search string, shipping address, survey response, etc.
- *Configure browser*: Add bookmark, set helpers, change cache size, scroll, etc.
- *React to environment*: respond to dialog, respond to display change, reload, etc.

Choo and Turnbull (2000) examined information seeking behavior of information managers on the web to develop a model of browsing and searching, and Kalbach (2001) has developed specific design criteria using this web model; nevertheless, how these criteria and suggestions relate to the overarching model is not clear. However, in the end these models of hypertext IR seem more a collection of empirical, grounded theory observations. The suggested design criteria appear to be mainly the application of accepted engineering psychology, human engineering criteria, and software engineering practices.

Stratified Model of IR Interaction

One of the more developed models is the stratified model (Saracevic, 1996). Theoretically, it draws on communication concepts in human – computer interaction and stratification theory in linguistics and communication. The stratified model views the interactive-searching process as a dialogue between participants, which are the user and the computer system. The dialogue is defined as a sequence of events in time toward some result. Each of the participants, user and system, has different levels or strata. Interaction is defined as the interplay between various strata over time. The dialogue occurs within these connected strata, converging at the surface stratum. The exchange of information between participants in the dialogue occurs through an interface at a surface stratum.

Saracevic (1996) discusses three strata for the user, which are: situational, affective, and cognitive. At the situational stratum, the user interacts with the given situation or problem that produced the information need. The results of the search may be applied to a resolution of the information need. The situation was the reason for the interaction to start, and the situation may be ill defined. A user brings given states of knowledge, belief, intent, and motivation to the situation. These states may change during the dialogue.

On the affective stratum, users interact with their intentions and associated elements, such as beliefs, motivations, feelings, desires, and urgency.

At the cognitive stratum, users interact with the documents and information as cognitive structure. Cognitive processes at this stratum include interpretation, judgment, assimilation, relevance, and effects of changes in the state of knowledge. From an IR perspective, relevance is a key element at this stratum.

The strata on the computer side are engineering, processing, and content. The engineering level is the hardware along with the system's operational and design attributes. The processing level focuses on the software, especially the algorithms and approaches that underlie the system's IR processes. The content stratum concentrates on the information resources and their representation as made by the system.

The cognitive, affective, and situational aspects from the user strata and the engineering, processing, and content aspects from the system strata converge at the surface stratum, where the user makes utterances and receives

responses through the system interface. At the surface stratum, the user engages in searching, matching, browsing, navigating within and among information resources, and reviewing results. On the system side, the system interacts with the user and provides responses in this dialogue. As the dialogue progresses, the situation at the surface stratum changes as new search terms are added, old tactics abandoned, and new tactics utilized.

The strength of the stratified model, relative to other cognitive models in IR, is that it decomposes the interactions into different strata, and it simultaneously separates the different participants within each stratum. This method of decomposition permits the design characteristics to be more easily developed once each of the various components are isolated. One can view each component as a separate object with its own set of characteristics, which lends itself to coding and component design. Saracevic (1997) points out that a weakness of the stratified model, however, is the decomposition of the various strata.

Certainly decomposition is difficult at the cognitive, affective, and situational strata. However, what occurs at these strata may have little impact on the search process if it is not expressed at the surface stratum. From a system design view, concentrating on the actions that occur at the surface stratum and then relating these back to cognitive and situational levels may in part circumvent this shortcoming of the model. In the research reported here, the concentration for refinement of the stratified model is on these utterances at the surface stratum.

Conceptual and Theoretical Framework

Further development of the stratified model in order to aid IR system design must address at least three questions, which are modifications of questions raised by (Saracevic, 1996):

(1) What are the interactions occurring at the surface stratum?
(2) What do these interactions indicate about the cognitive, affective, and situational aspects of the user?
(3) How can the system utilize these interactions to improve performance?

With respect to question one, at the surface level, the stratified model currently focuses almost exclusively on the query, although mention is made of other interactions. This focus is similar to other cognitive models. For example, in the cognitive model (Ingwersen, 1992), the query is the exclusive exchange at the interface level. The stratified model also implies the dominance of the query by referring to 'utterances' at the surface level. In (Saracevic, 1997), the query is the only element depicted that summarizes elements from other strata of the user, and Saracevic states that the "query is the most important aspect of user modeling" (Saracevic, 1997, p. 323). However, investigations at the surface stratum can concentrate on other interactions between the user and the system.

Reviewing empirical studies of interactive searching, one finds the query only one of many actions that the user takes when interacting with information objects. Marchionini (1995) notes that the user examines results and extracts information. Byrne et al. (1999) notes that the user takes several actions, including reading, viewing, listening, saving, duplicating, and printing. In a hypertext environment, the user also goes back, goes forward, bookmarks, and views the history list. These actions are expressions of the user's reaction to the information the system presents. Some expressions may be positive; others negative; others neutral, and other actions may express states of uncertainty. There are some actions that obviously stand out as positive expressions of the relevance of the information presented. These include bookmark, copy, duplicate, print, and save.

If the IR system could utilize these positive expressions of relevance at the surface stratum, both the document that caused the expression and the query that presented the information object, the system would have additional information to assist the user in locating other relevant information. This assistance could include offering searching advice or suggesting other documents that match the query, among many other types of asssitance. If desired, the user could review and process this system-provided information, which could perhaps change elements at the user's cognitive, affective, and situational strata.

This is the approach taken in this research. The aim is to design an IR system that monitors for positive expressions or utterances of relevance by the user concerning the information presented during the search process. Based on these positive utterances, the system then presents to the user courses of action, also utterances, to satisfy the user's information need.

Research Design

We utilize the agent paradigm to imbue a fully functional IR system, MG (Witten, Moffat, &Bell, 1994) with (1) the ability to monitor user utterances at the surface stratum and (2) the ability to make utterances to the user on courses of action to improve the search process.

Interactive sessions between searchers and IR systems are typically extremely short both in terms of the number of queries and time (Silverstein, et. al., 1999) and user interests are extremely varied (Jansen, Spink, and Saracevic, 2000). A method of rapidly recording the user's utterances, drawing inferences from these actions, and presenting utterances back to the user was needed.

To accomplish these aims, a technique used in adaptive hypermedia systems in which the user's information need is represented by of a set of pairs (c, v) where c is a concept and v is a value (Eklund & Brusilovsky, 1998) is modified. A concept is an idea, a subject, a preference, a submission or a topic. A value is a measure that associates the user to that concept, such as a Boolean or a numeric indicator.

This approach is altered for use in extending the stratified model. A series of action - object pairs (a, o) represents a user's pattern of utterances during a session. The agent currently monitors the surface level for five actions (a), stated as a is an element from the set {bookmark, copy, print, save, submit}. There are currently three objects (o) that the agent recognizes, stated as o is an element from the set {documents, passages from documents, queries}.

The valid object in the *(a, o)* pair varies with the type of action. Document objects are applicable to the actions of bookmark, print, and save. Passage objects are applicable to the action copy, and query objects are applicable to the action submit. For example, if a user bookmarks a file (e.g., Readings in IR), the *(a, o)* pair would be (*bookmark Readings in IR*). The agent records the series of *(a, o)* pairs during a session, and then offers assistance based on the series of *(a, o)* pairs recorded. Using this approach, one can model the user's information desires relatively rapidly.

Assistance Offered by the Agent

It was necessary at this stage of the research to narrow the agent's assistance, given the scores of user – system interaction issues (Borgman, 1996; Yee, 1991). The agent focuses on five areas of assistance, which are modifications to query structure, spelling corrections, synonyms and term context, changing the query to either increase or decrease the results list, and term relevance feedback. The agent communicates with the user via an interface button. The user can view the agent information or ignore the feedback notification with no impact on the normal operation of the IR system.

Empirical Test

To evaluate whether or not the utilization of utterances at the surface level could improve system performance, the performance of the MG system and the MG – agent system was contrasted. No MG code was modified to integrate the agent other than establishing the application program interface. The MG and the MG-agent system ran on the same computer, displayed the identical interface, and utilized the same document collection. Both systems were installed on a SPARC book 3 running Solaris 2.5. The subjects for the evaluation were 30 freshman college students, 26 males and 4 females. The document collection utilized for the testing was the Text Research Collection (TREC), volumes number 4 and 5, which are approximately 2GB in size and contain approximately 550,000 documents.

Viewing this evaluation as a preliminary evaluation, two TREC topics were chosen, *Number 301: International Organized Crime* and *Number 340: Land Mine Ban*. There were 555 relevant documents (1%) in the collection. For this research, the interest was the agent's effect on precision within the top 20 ranked documents. Thus, if more than 20 documents were returned for a particular query, documents numbered 21 and higher in the results list were ignored. If the query returned fewer than twenty documents, that number was utilized to calculate precision for that particular query.

The 30 subjects utilizing the two search topics and both IR systems generated 175 unique queries. There were 81 unique queries executed on the MG system and 94 unique queries executed on the MG – agent system. Each session was five minutes in duration. All searchers utilized the agent feedback at least once during the session. Precision for each set of unique queries executed on each system was calculated and analyzed, utilizing the documents that the user identified as relevant and the TREC relevant documents. Our analysis revealed a difference between the two sets of queries (paired $t = -3.417$; $p < 0.01$), with the precision of the MG – agent system performing significantly better than the precision performance of the base system. However, the performance of both systems was less than desirable (precision = 10% for the MG and 30% for the MG –agent system). Further evaluation will be needed for statistically meaningful results (e.g., more topics, longer sessions, etc.).

Conclusion and Significance of Research

In refining the stratified model, utterances at the surface stratum that shed light on the cognitive, affective, and situational strata during the information retrieval process were identified. An IR system was successfully modified to use these surface utterances to assist the user in the search process. The (a, o) development technique permitted the extrapolation of user notions of relevance based on utterances at the surface stratum. Utilizing the (a, o) pair model, the agent provides this searching assistance solely from using the normal actions of a searcher during the session. The user performs no additional actions during the search process to obtain this assistance. Evaluation of the modified system demonstrates that implementation of the stratified model may be a feasible avenue of research and may lead to improved support of IR systems during the searching process.

The next step is to refine the types of assistance provided and relate specific utterances to specific information needs. The danger is in increasing the type of searching assistance too much. Although one might assume that as searching features increased so would system performance, Saracevic and Kantor (1988) have shown that the increased use of advanced features may have an adverse effect on search performance.

The (a, o) pair model of user system interaction is being refined. Jansen, Spink, and Saracevic (2000) classified search–user interactions on a web system and isolated sequencing of action. Spink, Jansen, and Ozmultu (2000) also examine the sequence of users actions on web systems, focusing on relevance feedback. By relating these utterances to the cognitive, affective, or situational strata, the hope is to further develop the (a, o) pair model to identify session patterns in addition to individual utterances during a session.

The research presented in this article is the first step in implementing a cognitive model of interactive IR. Overall, the results of the research conducted so far are promising. They indicate that the stratified model of IR can be refined to a granularity that can positively affect system design. Using this model in conjunction with advanced computer technology, IR systems can become active participants in the information-seeking dialogue.

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